Deceleration in The Micro Traffic Model and Its Application to Simulation for Evacuation from Disaster Area

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Abstract

Referring to the Nagel–Schreckenberg's (NaSch) model, we have studied the impact of agent and diligent driver into the micro traffic model in the case of evacuation. This study is attention to the deceleration that added in the micro traffic model. The effect of deceleration to simulation for evacuation from disaster area is considered. The traffic flow property is studied by analyzing the time-space diagram. The simulation results show that deceleration caused the evacuation time increases when we compare it by without deceleration.

Keywords: deceleration, agent and diligent driver, micro traffic model, evacuation.

1. Introduction

The traffic dynamics model has attracted much attention of researchers in the fields of statistical physics and applied mathematics by using the advancement of computer technology [1-5]. The models can be divided in two kinds, continuous and discrete. Some continuous models have been carried out to explain the empirical findings [6-8] [4]. While the discrete models that have simpler structure than the continuous models and have fast performance in simulating have been widely used to model traffic flow, they have used the cellular automata (CA) approach. In 1992, Nagel and Schreckenberg (NaSch) proposed a traffic cellular automata (TCA) model for single-lane traffic flow that was able to reproduce several characteristics of real-life traffic flows, e.g., the spontaneous emergence of traffic jams [9]. The NaSch model contains four consecutive steps: acceleration, deceleration, randomization and vehicle movement. The NaSch model is a minimal model in the sense that all the four steps are necessary to reproduce the basic features of real traffic flows. The additional rules have been added to the NaSch model by researchers depending on their field of study. One of extension has been conducted related with the driving behavior; it is about diligent driver [10-12]. They have reflected diligent driver as an additional speed in the micro traffic model and implemented to simulation for evacuation from disaster area to get the effect of diligent driver towards the evacuation time. The other extensions pay attention to the deceleration step [13-15]. They have assumed that a vehicle has an expectation effect on the leading vehicle, so the velocity is not restricted by the current gap.

In connection with the deceleration, a vehicle has a limited capability of deceleration, it can't suddenly drop its velocity and it has to decelerate in advance to avoid a collision with the leading vehicle [15-16]. A model considering the limited capability of deceleration had been presented by [16]. They expressed the safe driving equation in a complex form. Otherwise, a simple method to reflect the deceleration in advance effect had been proposed by [15]. They stated that, to keep safe driving, a vehicle has to decelerate its velocity when it drives at a higher speed than the leading vehicle. The velocity of the vehicle may be restricted by a lower value than the current space gap.

In this study, we have added deceleration in advance to the traffic model in the previous work by referring to the [15]. The effects of deceleration have been considered by using various numbers of diligent drivers in the case of evacuation from disaster area.

2. Model

As we said in the previous section that the NaSch model [9] is one kind of the discrete model for traffic flow. By using CA, they presented a simple traffic flow model for one lane of traffic. The road is divided into L cells on a one-dimensional array in which each cell can be either empty or occupied by a vehicle. The velocity of each vehicle is v = 0, 1, …, or $v_{\max}$. All vehicles move from the left to the right with periodic boundary conditions. At each discrete time step $t \to t+1$, all the vehicles simultaneously update their states according to three consecutive rules [17] (note that the original formula of NaSch model [9] had four rules, they had separated acceleration and breaking):

(R1) *acceleration and braking*

$$v_i(t+1) \to \min\{v_i(t)+1, v_{\max}, gs_i(t)\} \quad (1)$$

(R2) *randomization*

$$v_i(t+1) \to \max\{0, v_i(t)-1\} \quad (2)$$

with probability p

(R3) *vehicle movement*

$$x_i(t+1) \to x_i(t)+v_i(t+1) \quad (3)$$

In which v_i and x_i denote the velocity and position of the i^{th} vehicle respectively; while $v_{\max}$ is the maximum velocity; $gs_i = x_{i+1} - x_i - 1$ denotes the number of empty cells in front of the i^{th} vehicle; and p is the randomization probability (sometimes called slowdown probability), it has the meaning that if a random number [0:1] is lower than p, the randomization occurs.

Based on [15], a vehicle will decelerate in advance when its velocity is higher than the leading one. The driver estimates the velocity difference Δv^e, when $\Delta v^e > 0$ means that the current (following) vehicle is approaching the leading one. If the velocity of the follower and the leader do not change, the gap should be $gs_i(t)$ - Δv^e at time step t + 1. They proposed that the driver will decelerate in advance when $\Delta v^e > 0$, so the gap at time step t + 1 should be lower than $gs_i(t)$ and larger than $gs_i(t)$ - Δv^e. Then the estimated gap at time step t+1 is determined by $gs_i^e(t) = \max\left(0, gs_i(t) - \lfloor \alpha \Delta v^e \rfloor\right)$. In which the floor function $\lfloor x \rfloor$ is defined by the largest integer no larger than x; α denotes a constant value and in this study, we use α =0.5. The velocity of the following vehicle will be restricted by the estimated gap. If the condition is $\Delta v^e \leq 0$, it means that the leading vehicle is driving away; the follower does not have to decelerate.

Referring to the estimated gap above, for two lanes of traffic, a modified NaSch model by considering deceleration in advance is proposed by the following rules:

(1) *acceleration*

$$v_{i,j}(t+1) \to \min\{v_{i,j}(t)+1, v_{\max}\} \quad (4)$$

(2) *determine the estimated gap*

If ($\Delta v_{i,j}^e > 0$), $gs_{i,j}^e(t) = \max\left(0, gs_{i,j}(t) - \lfloor \alpha \Delta v^e \rfloor\right)$,

else $gs_i^e(t) = gs_i(t)$ (5)

where α =0.5;

(2) deceleration/*braking*

$$v_{i,j}(t+1) \to \min\{v_{i,j}(t)+1, v_{\max}, gs_i^e(t)\} \quad (6)$$

(3) *randomization*

$$v_{i,j}(t+1) \to \max\{0, v_{i,j}(t)-1\} \quad (7)$$

with probability p

(4) *vehicle movement*

(i) *with lane-changing*: determine probability of lane-changing P_{lc}; a security criterion = [-v$_{\max}$: v+1].

$$g_{s;i=1,j}(t) \leq v \wedge x_{i=2,j,[-v_{\max}\,:\,v+1]}(t) = 0 \Rightarrow x_{i=2,j}(t+1) \leftarrow x_{i=1,j}(t) \quad (8)$$

or

$$g_{s;i=2,j}(t) \leq v \wedge x_{i=1,j,[-v_{\max}\,:\,v+1]}(t) = 0 \Rightarrow x_{i=1,j}(t+1) \leftarrow x_{i=2,j}(t) \quad (9)$$

Then vehicle movement:

$$x_{i,j}(t+1) \to x_{i,j}(t) + v_{i,j}(t+1) + [0:1] \quad (10a)$$

$$x_{i,j}(t+1) \to x_{i,j}(t) + v_{i,j}(t+1) \quad (10b)$$

where (10a) and (10b) denote vehicle movement for a diligent and ordinary driver, respectively.

(ii) *without lane-changing*:

Vehicle movement such as in Equation (10a) and (10b).

3. Time-Space Diagram

In the time-space diagram, horizontal axis shows the space and vertical one is the time. All vehicles move from left to right. Each new line shows the traffic line after one further complete velocity-update and just before the vehicle motion. The time axis shows the evacuation time, its value increases from up to bottom.

In Figure 1, two pictures on the top is time-space diagram without deceleration in advance. While two pictures on the bottom show time-space diagram with deceleration in advance. In this time-space diagram, time (vertical) and space (horizontal) axes are oriented from the top to the bottom and the left to the right, respectively. As time advances, vehicles move from the left to the right (to the lower right corner), whereas congestion waves move to the upper left corner, i.e., backwards in space. This simulation for the low vehicle density k = 0.2, slowdown probability p = 0.1, and diligent driver dd = 0.8.

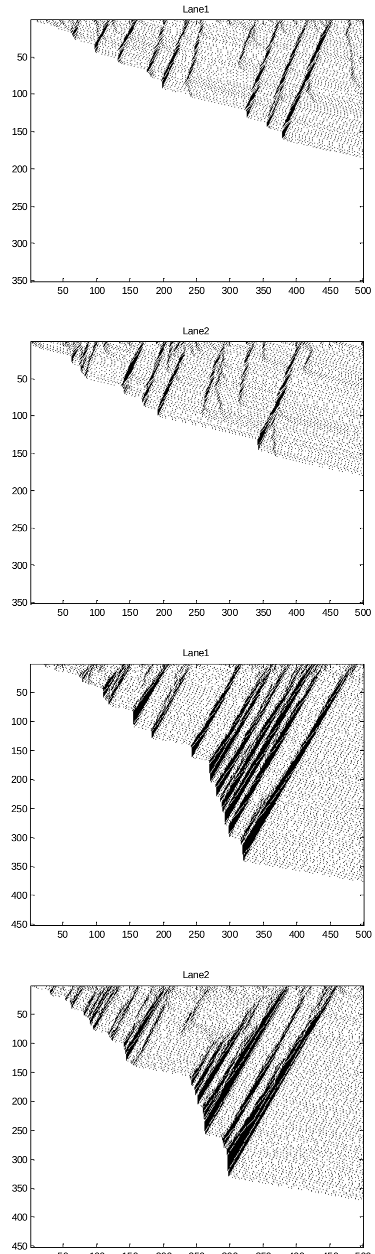

Figure 1 Time-space diagram of the traffic using density k = 0.2; lane-changing lc = 1; diligent driver dd = 0.8; and slowdown probability p = 0.1. *Two Top sides*: without deceleration (for lane 1 and 2 respectively); *Two Bottom sides*: with deceleration (for lane 1 and 2 respectively).

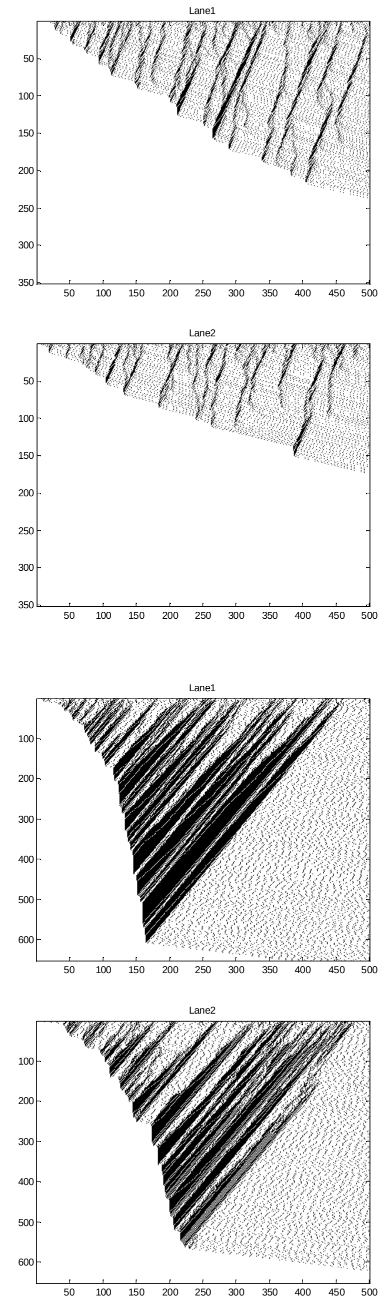

Figure 2 Time-space diagram of the traffic using density k = 0.2; lane-changing lc = 1; diligent driver dd = 0.8; and slowdown probability p = 0.2. *Two Top sides*: without deceleration (for lane 1 and 2 respectively); *Two Bottom sides*: with deceleration (for lane 1 and 2 respectively).

We see that both, with and without deceleration in advance, there is congestion wave with the opposite direction to the vehicle movement.

In these results, the evacuation time without and with deceleration in advance is found at 186 and 377 respectively. Thus, with deceleration in advance in this case, the evacuation time increases about double when it is compared by the result without deceleration.

Figure 2 also sees the time-space diagram using different *p* (this result by *p* = 0.3 and value of the other parameters are same with Figure 1). We found that when the value of *p* increases, congestion wave also increases that shown by the black area in diagram. This happens in both, with and without deceleration in advance.

4. Simulation Results

Regarding with the real situation on Sidoarjo Porong roadway, the distance of the road from start position of the evacuation to the destination area (safe area) is 3500 m, it is as a road length *L*. In this work, *L* is assumed to be 500, so that the length of one site is set to 7 m. By referring to [9], one time step approximately corresponds to 1 second in real time.

The following section, we show relations between the evacuation time *T* and diligent driver *dd* without/with deceleration in advance, using selected vehicle density *k* and different of slowdown probability *p*.

4.1. For the vehicle density *k* = 0.2

For the low vehicle density *k* = 0.2; parameters $\bar{v}$ and *sd* for the initial velocity of each vehicle are 4 and 1, respectively. Figure 3 on the *top* side for *lc* = 0.3, we obtain that by the increase of *dd* from 0% to 100%, *T* decreases either without or with deceleration in advance. The evacuation time with deceleration in advance for each value of *dd* is larger than that the evacuation time without deceleration in advance.

The same condition is also experienced for both: *lc* = 0.5 and 0.8. When *dd* increases, we find *T* decreases either without or with deceleration in advance (Figure 2 on the *middle* and the *bottom* side for *lc* = 0.5 and 0.8 respectively). We also find that the evacuation time with deceleration in advance for each value of *dd* is larger than that the evacuation without deceleration in advance.

4.2. For the vehicle density *k* = 0.5

For the intermediate vehicle density *k* = 0.5; parameters $\bar{v}$ and *sd* for the initial velocity of each vehicle are 3 and 1, respectively. For *lc* = 0.3, we find that *T* decreases as *dd* increases from 0% to 100%, *T* decreases either without or with deceleration in advance (Figure 4 on the *top* side). As condition occurred in the low vehicle density, in this vehicle density also happen that the evacuation time with deceleration in advance for each value of *dd* is more increase than that the evacuation time without deceleration in advance.

When we use the value of *lc* = 0.5 and 0.8, the same trend of the evacuation time is obtained. It means that by the increase of *dd*, we find *T* decreases either without or with deceleration in advance (Figure 3 on the *middle* and the *bottom* side for *lc* = 0.5 and 0.8 respectively). We also can see that the evacuation time with deceleration in advance for each value of *dd* is larger than that the evacuation without deceleration in advance.

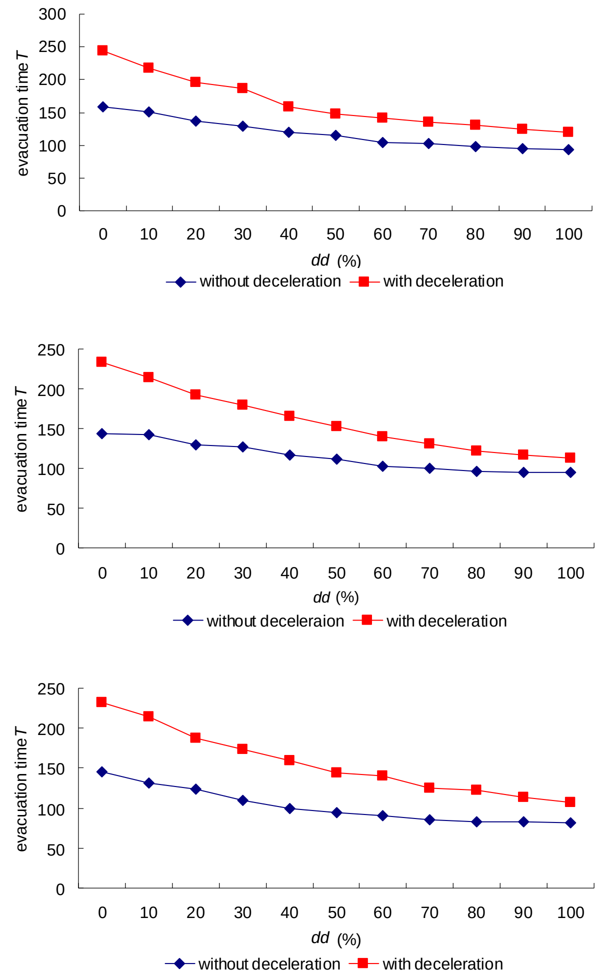

Figure 3 Relationship between diligent driver *dd* and evacuation time *T* without/with deceleration in advance, using *k* = 0.2; $\bar{v}$ = 4; *sd* = 1; *A* = 5. From the *top* side to the *bottom* side: using *lc* = 0.3, 0.5, and 0.8 respectively.

5. Conclusion

Deceleration in advance parameter has been incorporated into the micro traffic model besides agent and diligent driver. A modified NaSch model has been proposed by adding the deceleration in advance in the previous work. Traffic flow property has been presented by time-space diagram. In the context of its application to simulation for evacuation from disaster area, relationships between the evacuation time and diligent driver are investigated without and with deceleration in advance.

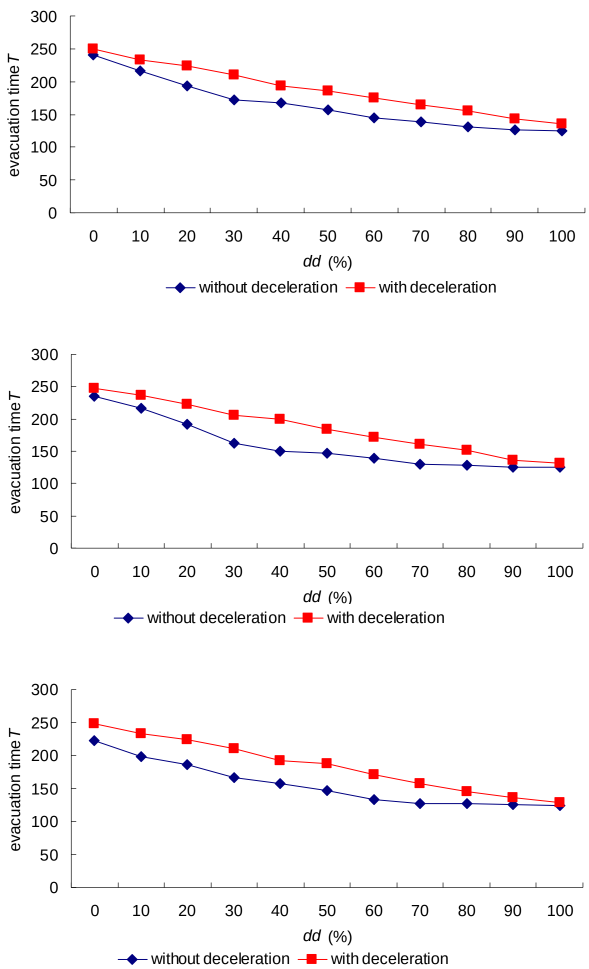

Figure 4 Relationship between diligent driver *dd* and evacuation time *T* without/with deceleration in advance, using k = 0.5; $\bar{v}$ = 3; *sd* = 1; *A* = 5. From the *top* side to the *bottom* side: using *lc* = 0.3, 0.5, and 0.8 respectively.

The simulation results found the effect of deceleration in advance with respect to the evacuation time. Regarding relations between evacuation time and diligent drivers have been obtained that with the increase of diligent drivers, evacuation time decreases without/with deceleration in advance, either in the low vehicle density(k = 0.2) or in the intermediate one (k = 0.5). In these relations are also shown that the evacuation time with deceleration in advance more increase than that the evacuation time without deceleration in advance.

References

[1] S. Darbha, K.R. Rajagopal and V. Tyagi, "A review of mathematical models for the flow of traffic and some recent results", *Nonlinear Analysis: Theory, Methods & Applications*, Vol. 69, No. 3, pp. 950–970, 2008.

[2] E. López-Neri, A. Ramírez-Treviño and E. López-Mellado, "A modeling framework for urban traffic systems microscopic simulation", *Simulation Modelling Practice and Theory*, Vol. 18, No. 8, pp. 1145-1161, 2010.

[3] M.E. La´rraga a, J.A. del Rı´o b and L. Alvarez-lcaza, "Cellular automata for one-lane traffic flow modeling" *Transportation Research Part C: Emerging Technologies*, Vol. 13, No. 1, pp. 63-74, 2005.

[4] H.X. Ge, R.J. Cheng, and Z.P. Li, "Two velocity difference model for a car-following theory", *Physica A*, Vol. 387, No. 21, pp. 5239-5245, 2008.

[5] W. Knospe, L. Santen, A. Schadschneider and M. Schreckenberg, "An empirical test for cellular automaton models of traffic flow", *Physical Review E*, Vol. 70, No. 1, pp. 016115(1-25), 2004.

[6] M. Bando, K. Hasebe, A. Nakayama, A. Shibata and Y. Sugiyama, "Dynamical model of traffic congestion and numerical simulation", *Physical Review E*, Vol. 51, No. 2, pp. 1035-1042, 1995.

[7] D. Helbing and B. Tilch, "Generalized force model of traffic dynamics", *Physical Review E*, Vol. 58, No. 1, pp. 133-138, 1998.

[8] R. Jiang, Q. Wu and Z. Zhu, "Full velocity difference model for a car-following theory", *Physical Review E*, Vol. 64, No. 1, pp. 017101(1-4), 2001.

[9] K. Nagel and M. Schreckenberg, "A cellular automaton model for freeway traffic", *Journal Physics I France*, Vol. 2, No. 12, pp. 2221-2229, 1992.

[10] K. Arai and T. Harsono, "Car-following parameters by means of cellular automata in the case of evacuation", *International Journal of Computer Science and Security (IJCSS)*, Vol. 5, No. 1, pp. 638-648, 2011.

[11] K. Arai and T. Harsono, " Agent and diligent driver behaviour on the car-following part of the micro traffic flow in a situation of vehicles evacuation on

Sidoarjo Porong roadway, *International Journal of Computer Science and Network Security (IJCSNS)*, Vol. 11, No. 1, pp. 137-144, 2011.

[12] K. Arai, T. Harsono and A. Basuki, "Cellular automata for trafic modelling and simulations in a situation of evacuation from disaster area, One Chapter in *Cellular Automata – Simplicity Behind Complexity*", InTech Publisher, pp. 193-218, 2011.

[13] R. Jiang, M.B. Hu, B. Jia, R.L. Wang and Q.S. Wu, " The effects of reaction delay in the Nagel-Schreckenberg traffic flow model", *Eur. Phys. J. B*, Vol. B 54, No. 2, pp. 267-273, 2006.

[14] Xb. Li, Qs. Wu and R. Jiang, Cellular automata model considering the velocity effect of a car on the successive car", *Physical Review E*, Vol. 64, No. 6, pp. 066128(1-4), 2001.

[15] X.B. Li, Z.Y. Gao, B. Jia and R. Jiang, "Deceleration in advance in the Nagel-Schreckenber traffic flow model", *Physica A*, Vol. 388, No. 10, pp. 2051-2060, 2009.

[16] H.K. Lee, R. Barlovic, M. Schreckenber and D. Kim, "Mechanical restriction versus human overreaction trigerring congested traffic states", *Physical Review Letters*, Vol. 92, No. 23, pp. 238702(1-4), 2004.

[17] S. Maerivoet and B. De Moor, "Cellular automata models of road traffic, *Physics Reports*, Vol. 419, No. 1, pp. 1-64, 2005.